Fraunhofer Center for Sustainable Energy Systems

Thermal Performance Analysis of PCM-Enhanced Insulations

Jan Kosny Ph.D.

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Fraunhofer USA

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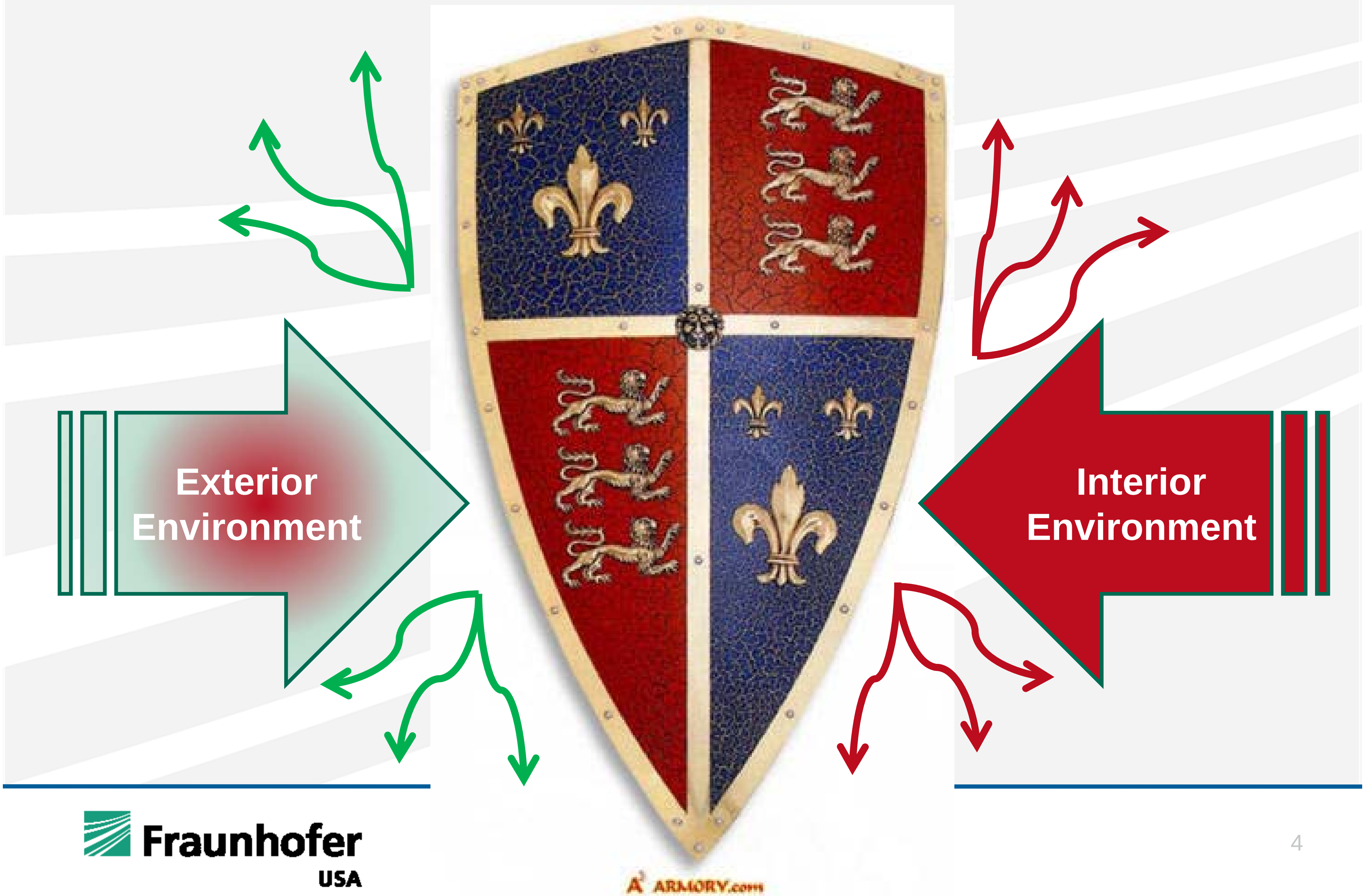
Agenda

- Introduction – A need for new thermal-design principles for modern buildings
- Motivation – A need for detailed thermal characteristics of new dynamic materials to be used in Building America projects
- Dynamic testing with use of Heat Flow Meter Apparatus
- New Performance Label for PCMs
- Potential for development of the material database for PCM products used in Northern America

Need for a New Thermal Design Principles for Modern Low-Energy Buildings

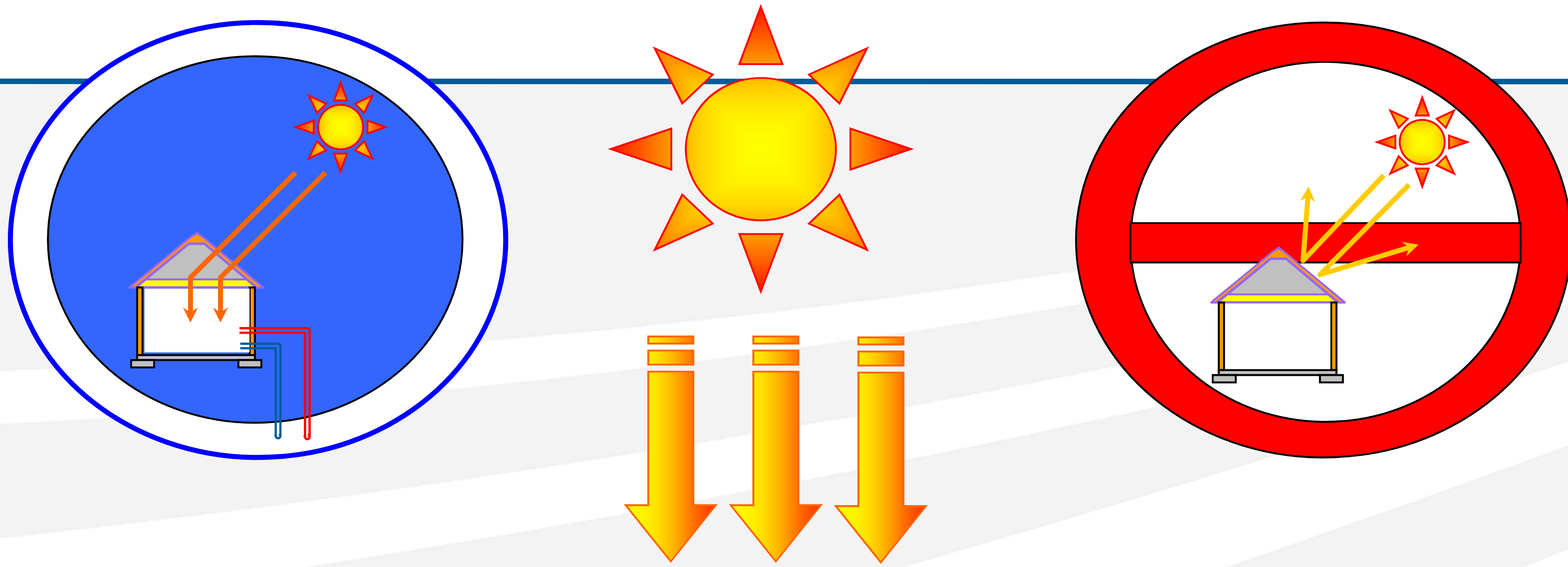
Today, Building Enclosures Work More as Thermal Shields



North American Houses are Currently Built Using

Igloo Principles - Developed for Large and Static Temperature Differences

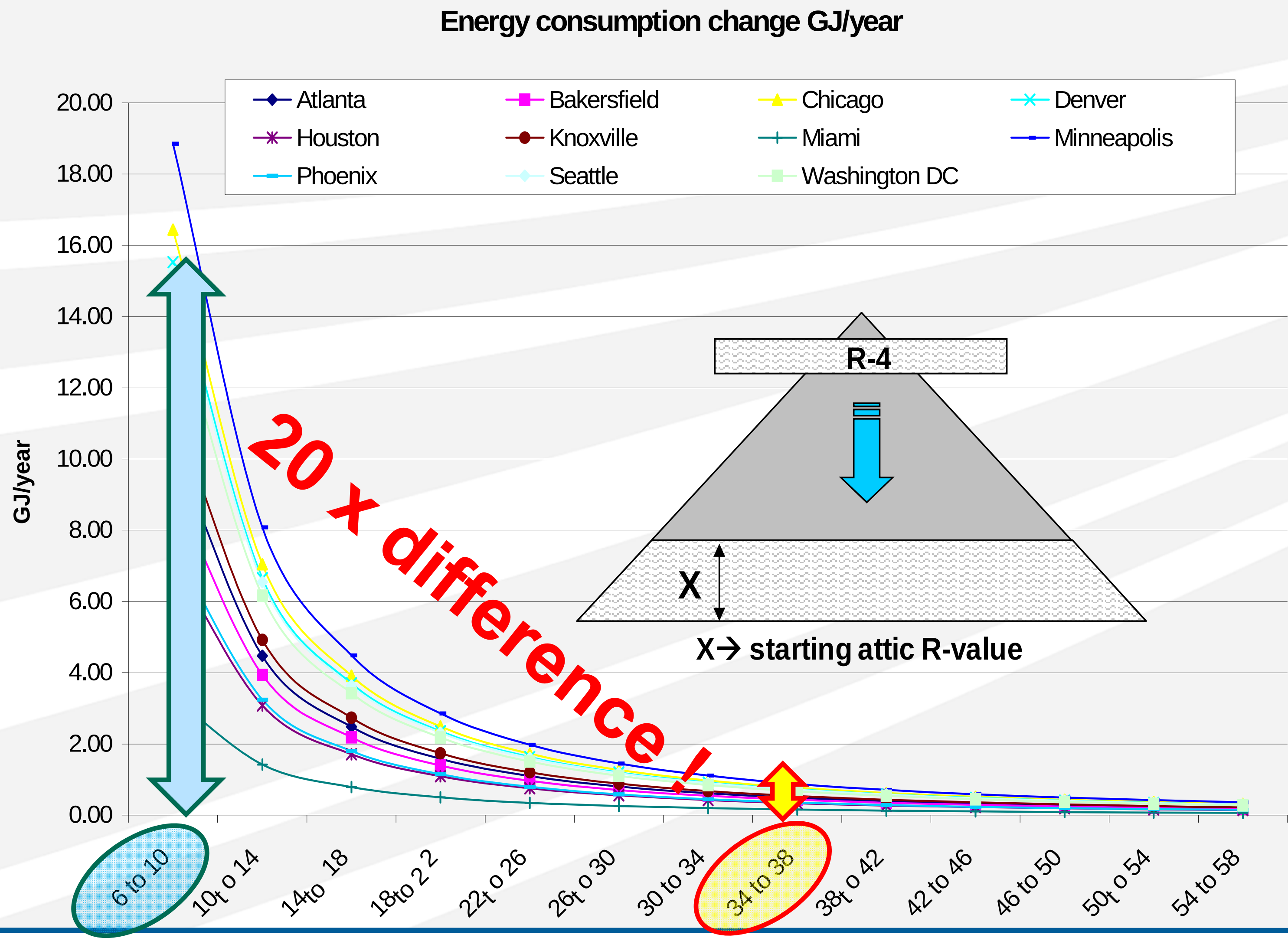
USA



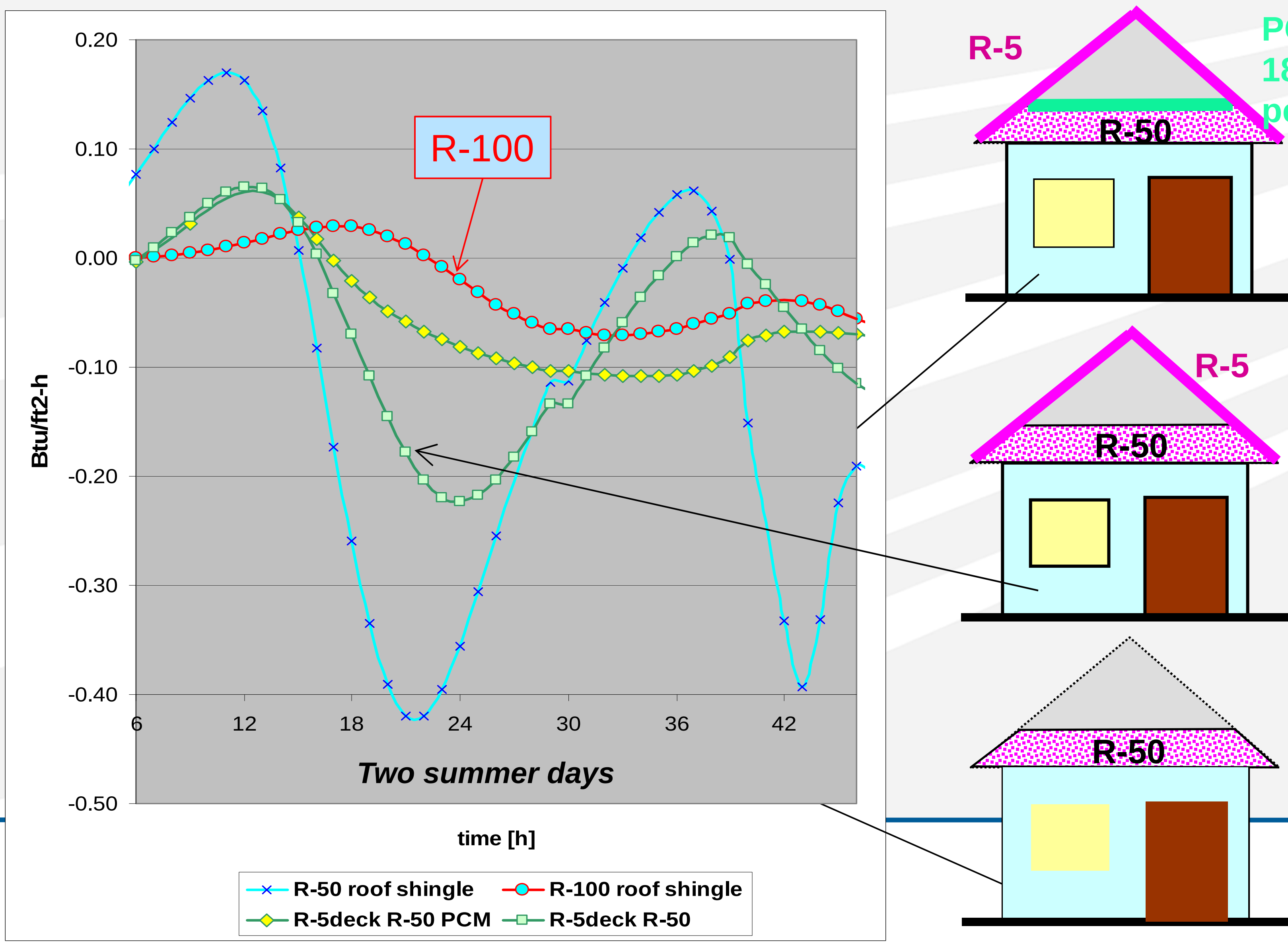
Energy Design Paradigm Proposed for Building America Projects

MOTIVATION (I): Conventional Insulations are not Always Efficient in High-R-value Assemblies

Example #1: Conventional insulation works only effectively for low R-value assemblies



Example #2: Performance of Conventional Insulations can be Easily Improved by Usage of Modern Insulation Configurations

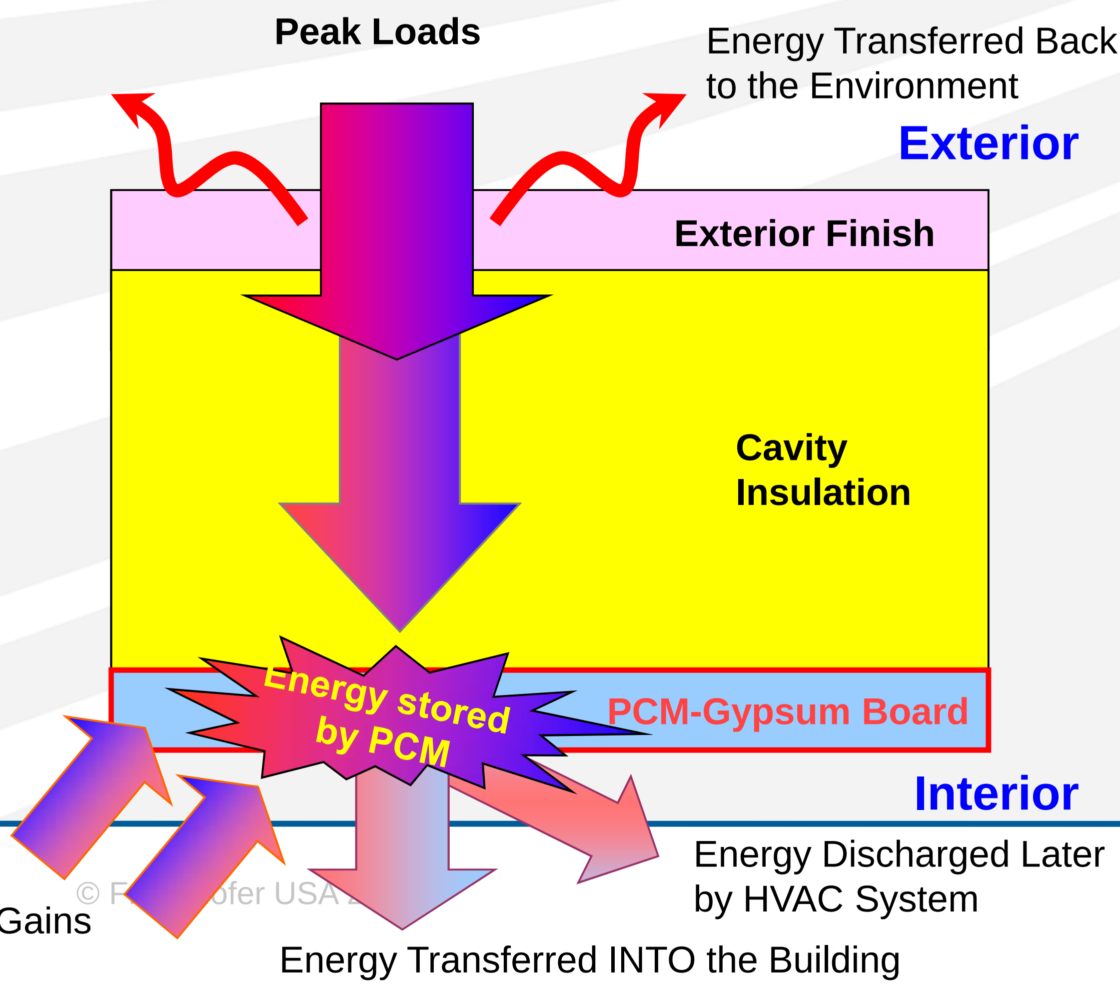


MOTIVATION (II):Several PCM-Enhanced Systems Successfully Used in Europe are Ineffective While Used in Northern America – Why?

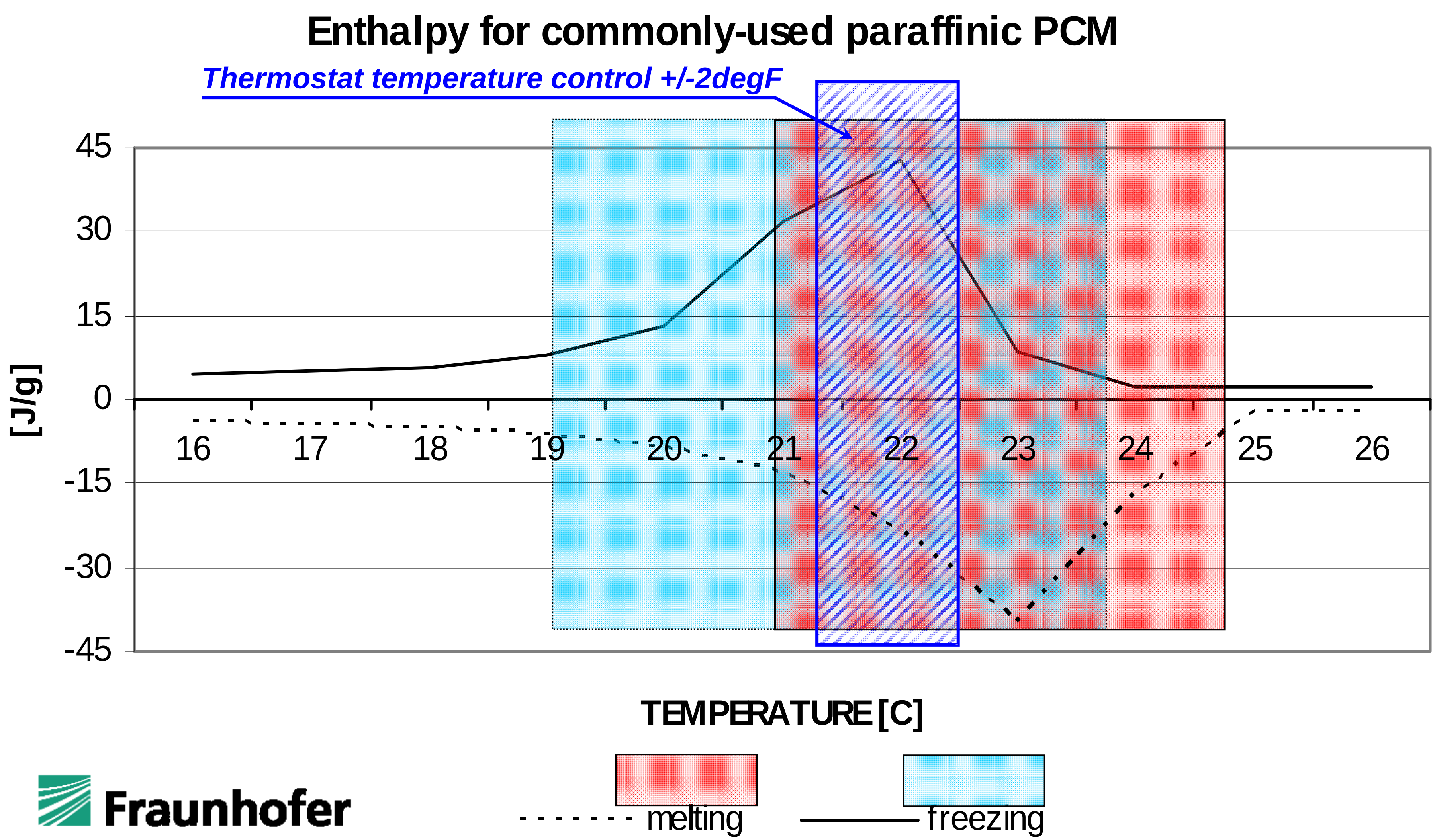
Old Approach – PCM-Impregnated Gypsum Board

- PCM charged by interior temperature swings and solar gains through glazing
- Building HVAC system used to discharge PCM

Schematic of Distribution of Heating and Cooling Loads in Old PCM Applications



Main Problem with Application of PCM Gypsum Boards in the U.S. Air-Conditioned Buildings



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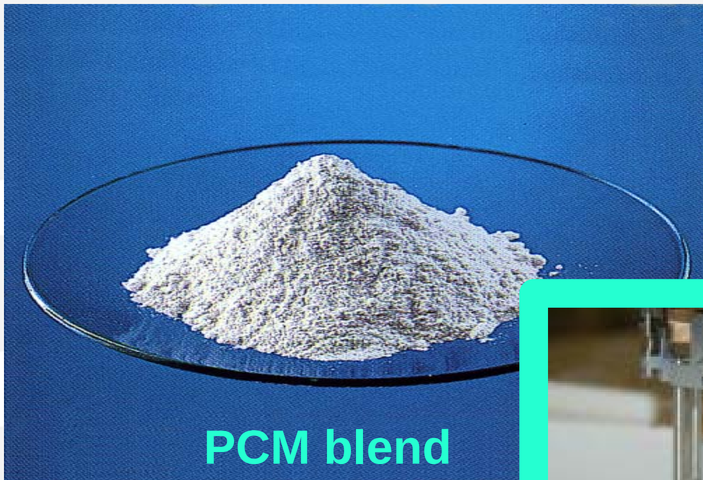
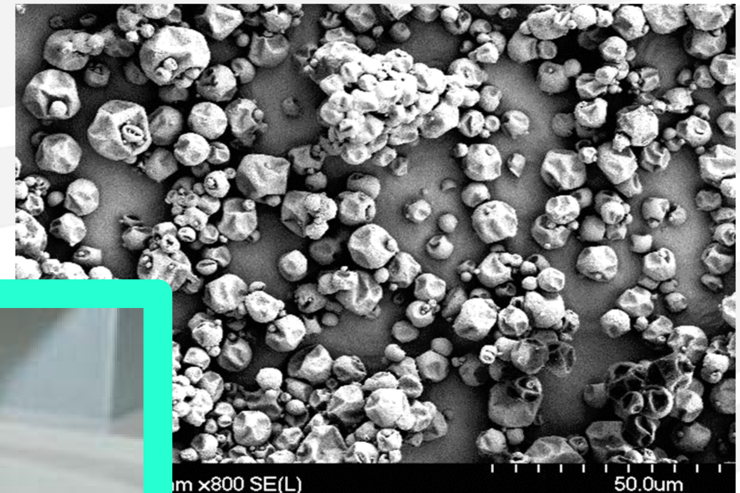
MOTIVATION (III): Traditional DSC Testing is NOT USEFUL for Many Non-Uniform and Complex PCM Products

Large Selection of **Non-Uniform PCMs** is in common use today which **cannot be tested in DSC**

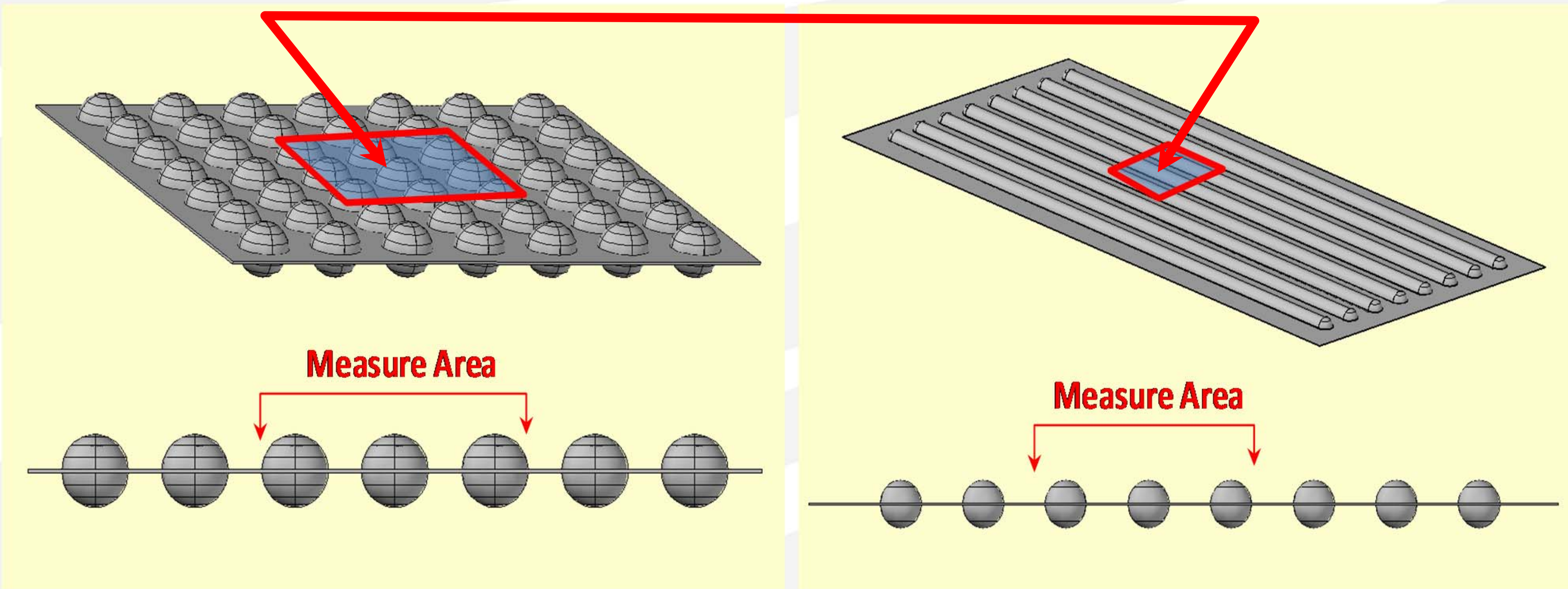




Complex arrays of PCM containers are extremely difficult to test in conventional equipment

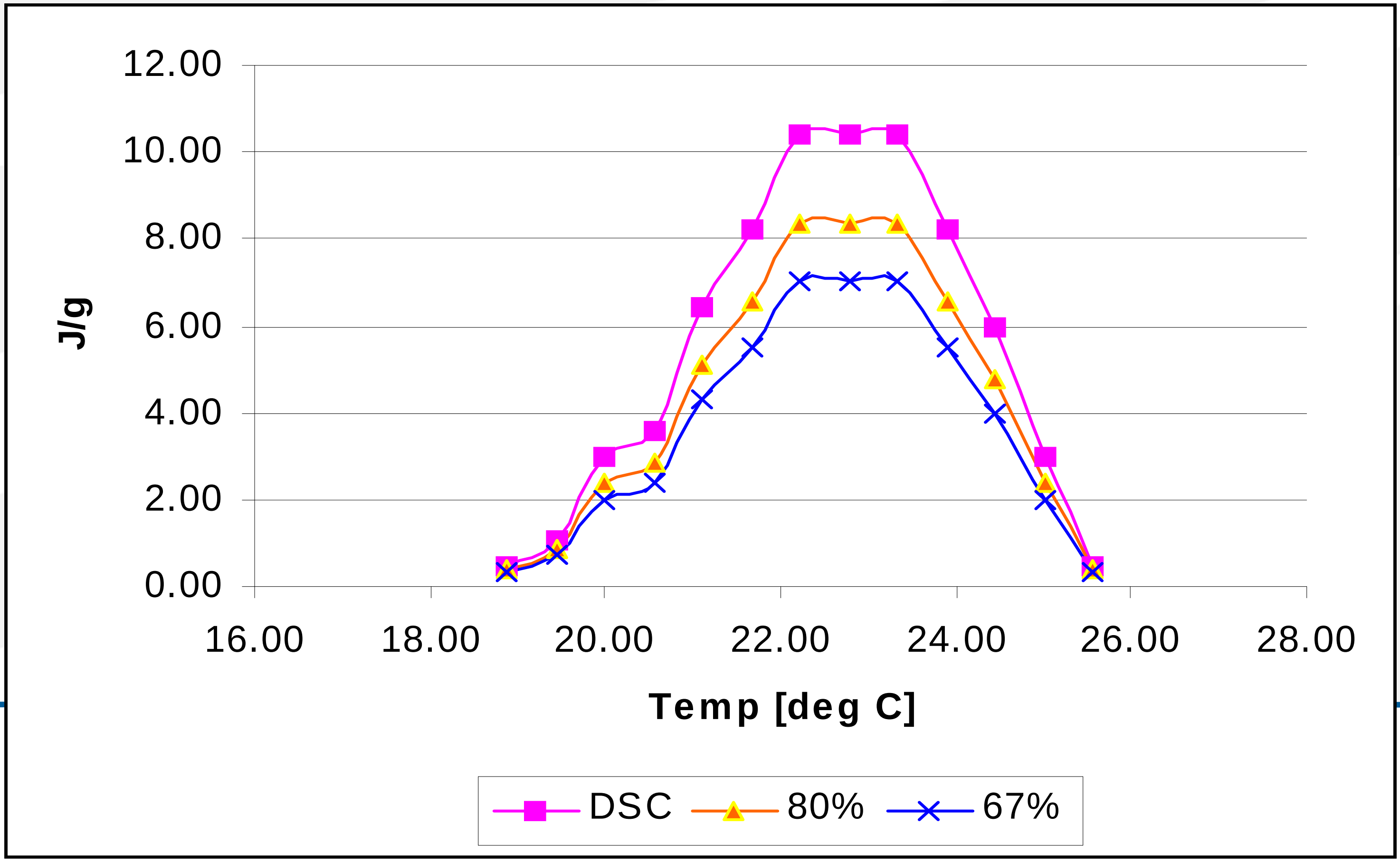
Example of estimation of the measure area for the arrays of PCM pouches or PCM containers.

Measure area needs to contain representative geometry of the measured array of PCM containers



Complexity of Δ–H Enthalpy Data for PCM-Enhanced Insulations and blends

- Initial Differential Scanning Calorimeter (DSC) tests for pure PCMs or PCM microcapsules, only
- **Additions to PCM-based blends make a difference;** Dynamic Heat Flow Meter Apparatus tests were introduced in 2006 for PCM-enhanced insulations - fire retardant effect, adhesives, not-working PCM pellets, etc….

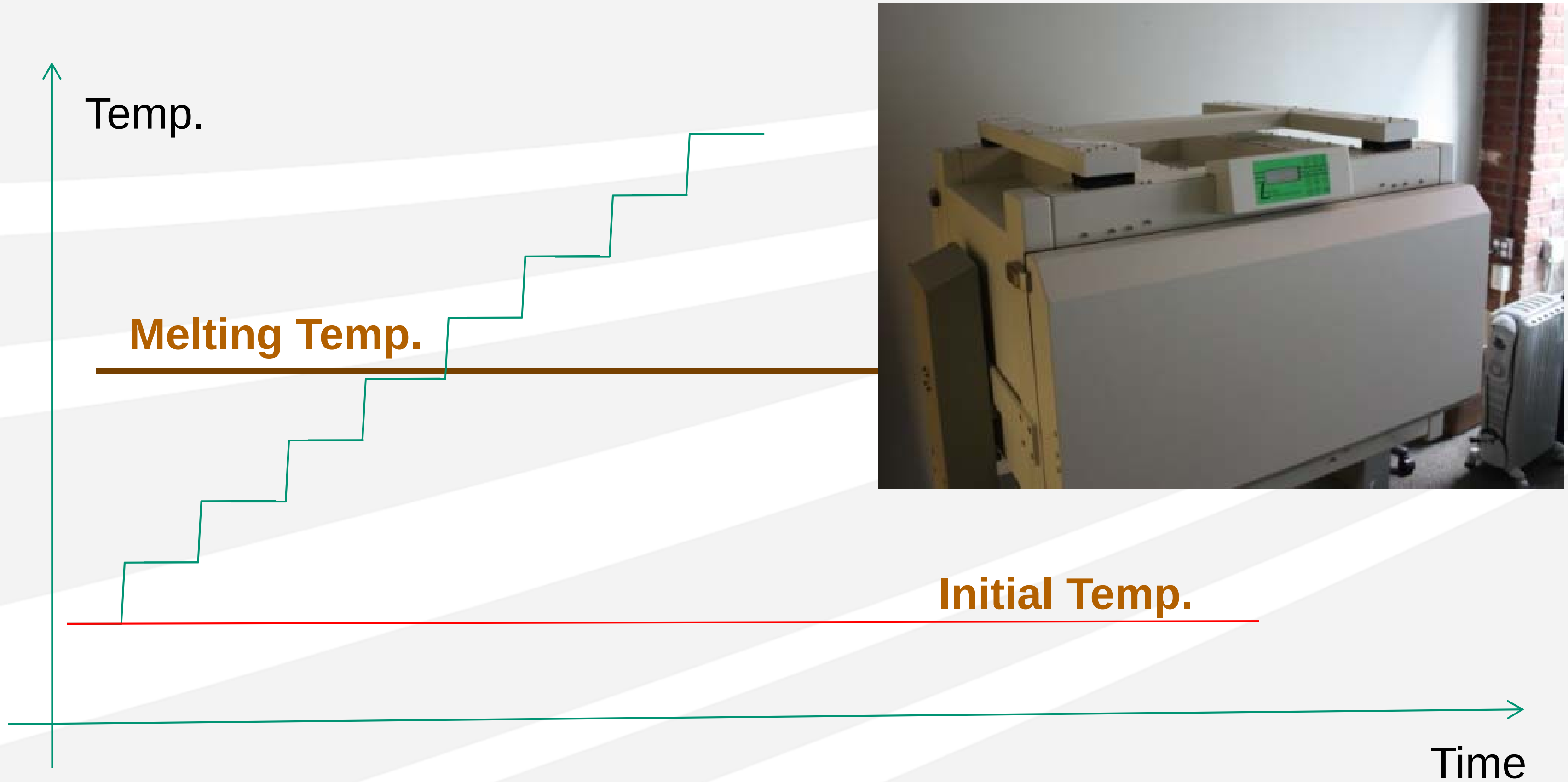


New Dynamic Test Method for PCM-Enhanced Products Developed by Fraunhofer CSE

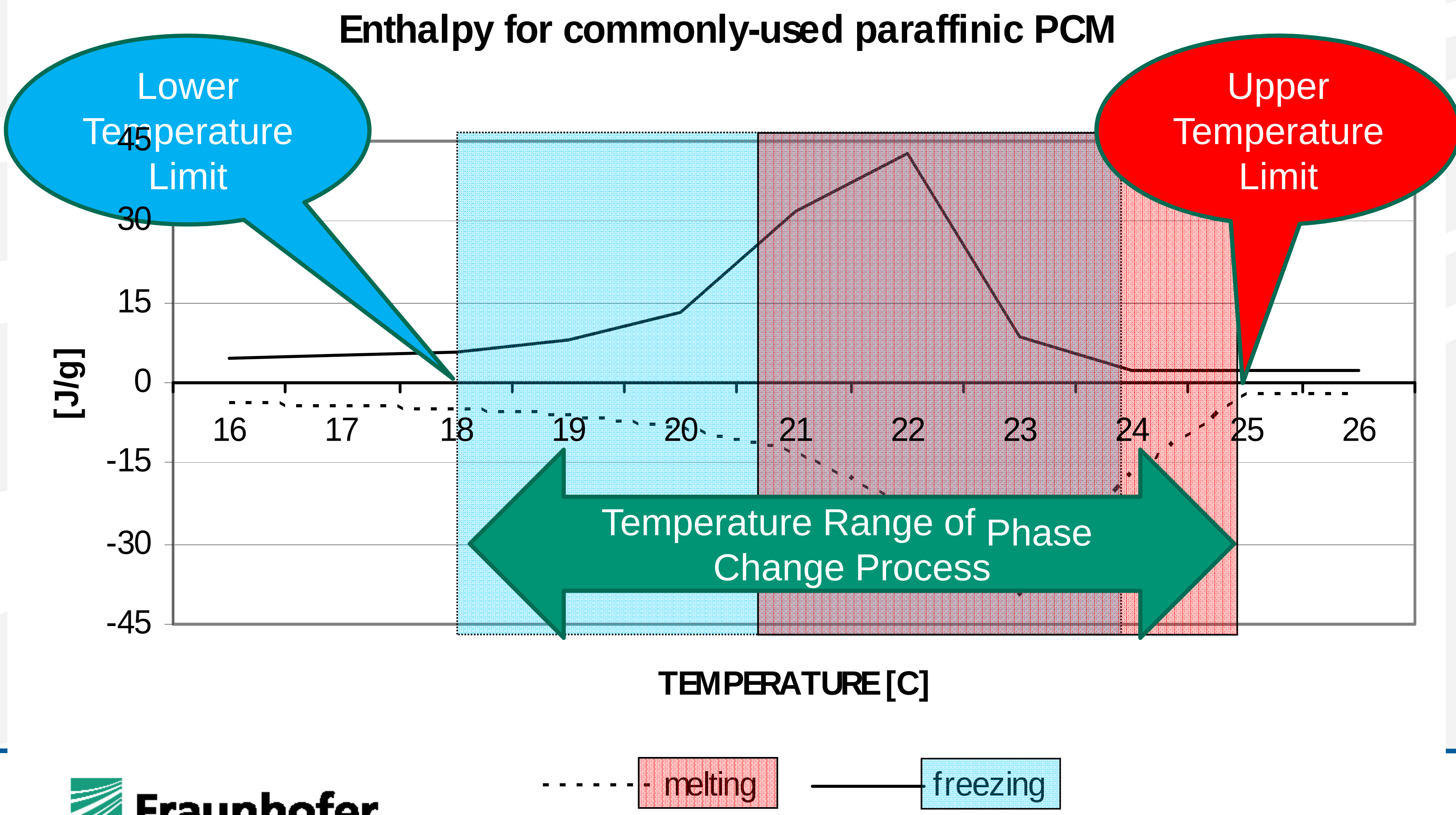
Dynamic Test Methods Considered Currently for Analysis of PCM-Enhanced Products

- DSC – only for uniform PCMs
- T-history method
- Dynamic Heat Flow Apparatus Method
  - Symmetrical process
  - Non-symmetrical process
- Dynamic Guarded Hot-Plate Method – only speculations so far
- Dynamic Hot-Box Method

Testing Temperature Profile Used by Fraunhofer CSE - Symmetrical Testing on Both Plates of the HFMA



Key Temperatures of the PCM Transition Process



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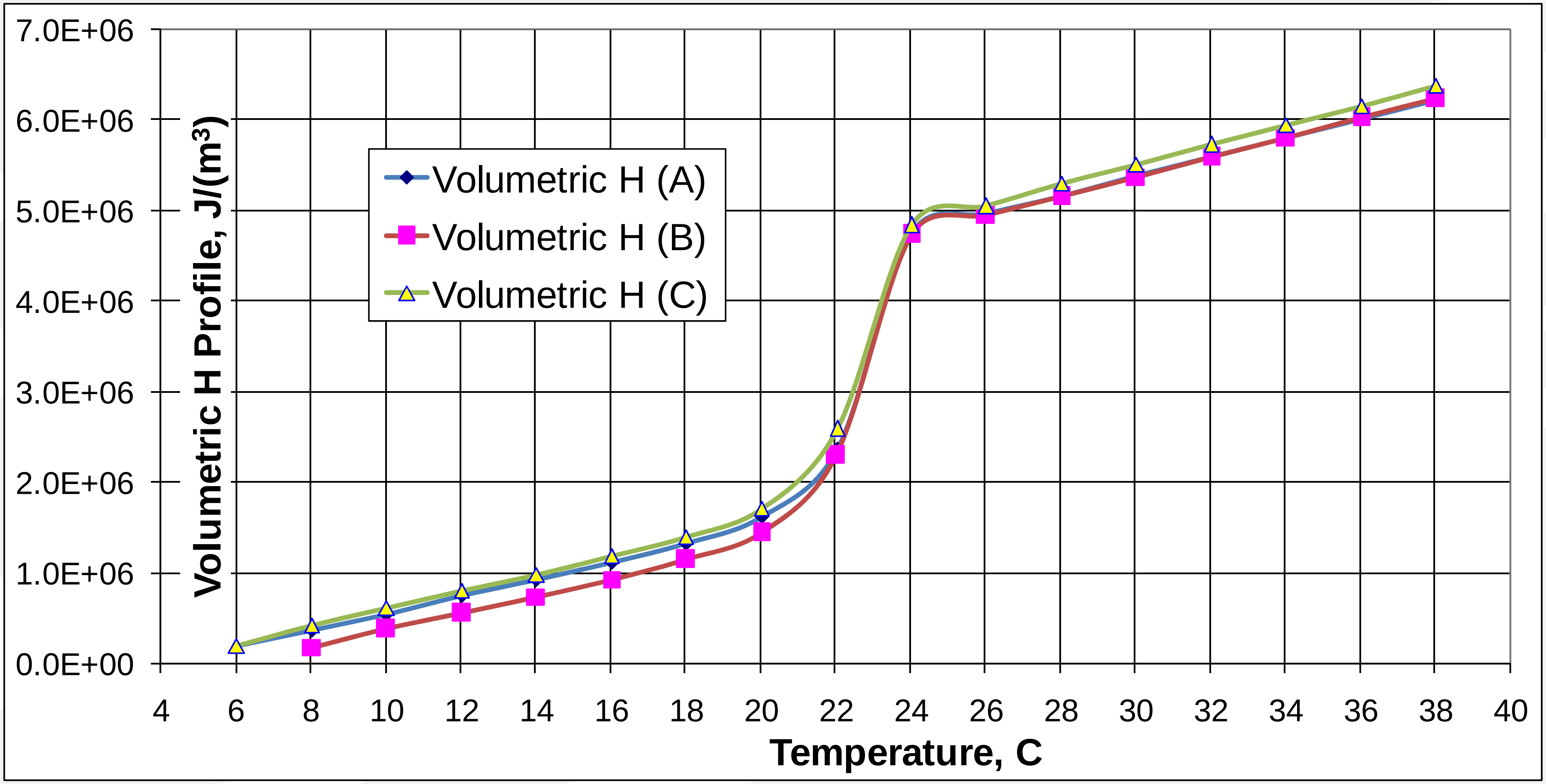
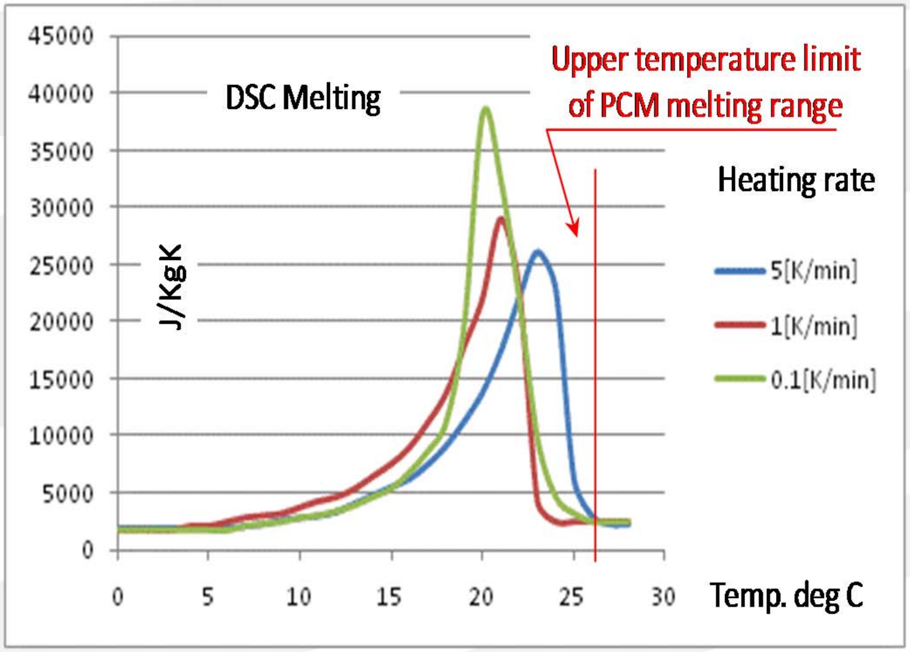
Enthalpy change profile developed during **Dynamic Heat Flow Meter Apparatus Testing**

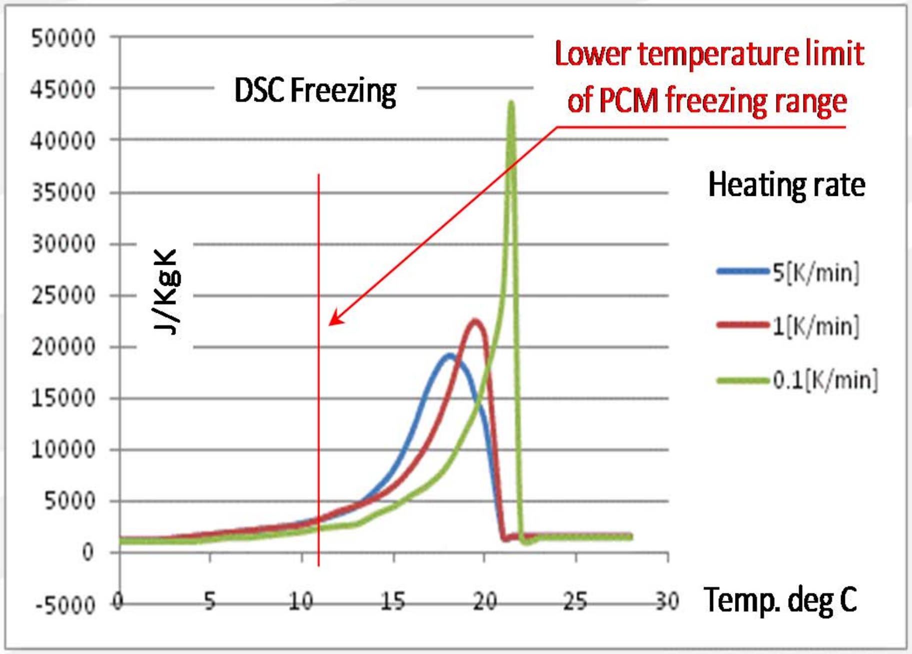


MOTIVATION (IV): Results from Traditional DSC Testing Can be Misused

Rate of Temperature Change Effects Enthalpy Profiles

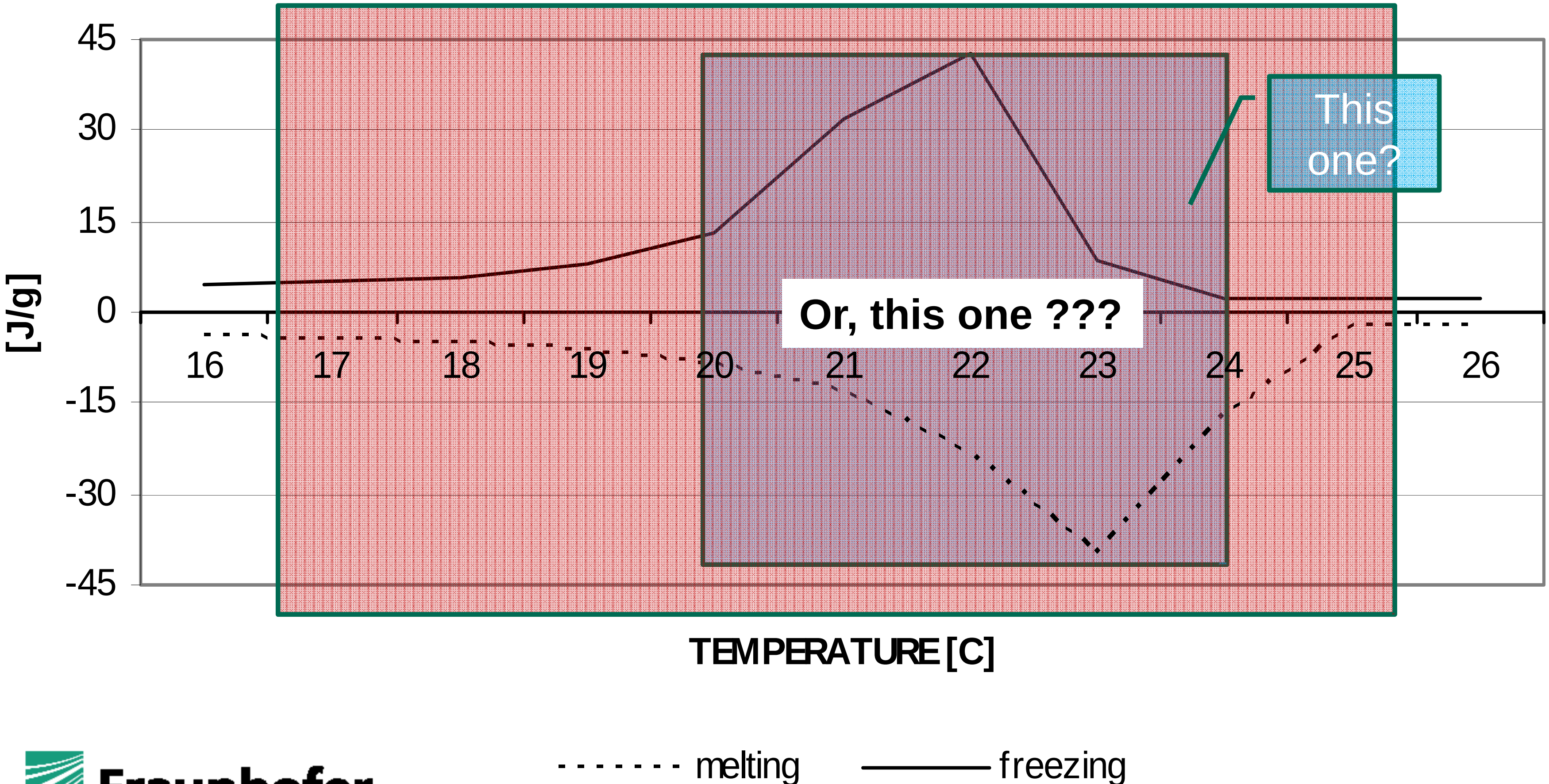
Estimation of upper and lower temperature limits for sample of the PCM-enhanced material or composites using original DSC test data for PCM (paraffinic PCM data shown).





Potential area for misuse of the experimental data on PCM-enhanced products for most-likely marketing purposes

For what temperature range PCM enthalpy should be calculated if c_p-related effects are included together with phase transition–related effects?



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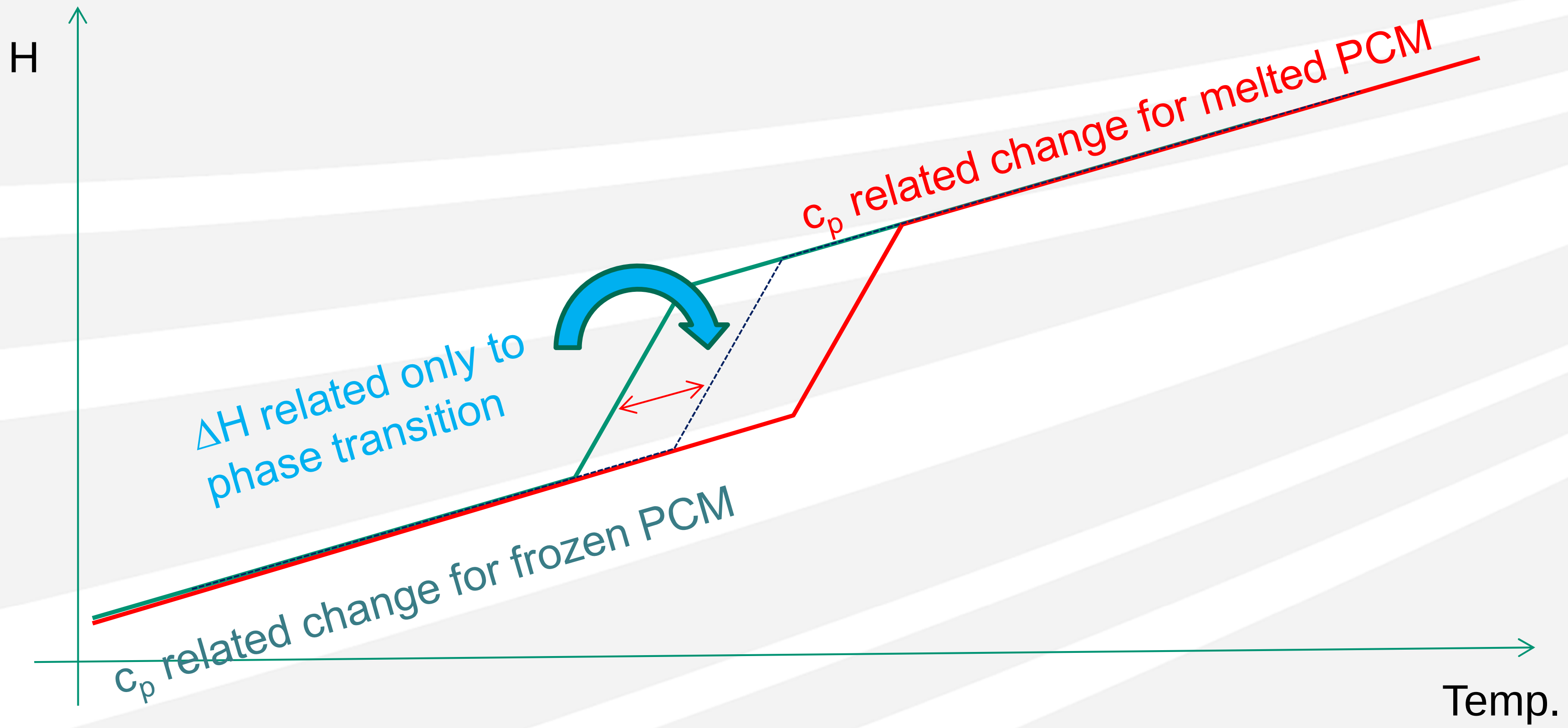
M-value – New Energy Performance Label for PCM-Enhanced Products

Expressing only phase transition-related enthalpy change

Understanding of **Enthalpy Profile** in estimation of M-value



It is possible to analytically estimate and later subtract c_p-related enthalpy changes for both frozen and melted stages of the testing.

Basic Heat Transport Equations:

The one-dimensional heat transport equation for such a case is as follows:

$$\frac{\partial}{\partial t}(\rho h) = \frac{\partial}{\partial x}\left[\lambda \frac{\partial T}{\partial x}\right]$$

where; ρ and λ are the material density and thermal conductivity, T and h are temperature and enthalpy per unit mass. Heat flux q is given by:

$$q(x,t) = -\lambda \frac{\partial T(x,t)}{\partial x}$$

The enthalpy derivative over the temperature (with consideration of constant pressure) represents the effective heat capacity, with phase change energy being one of the components:

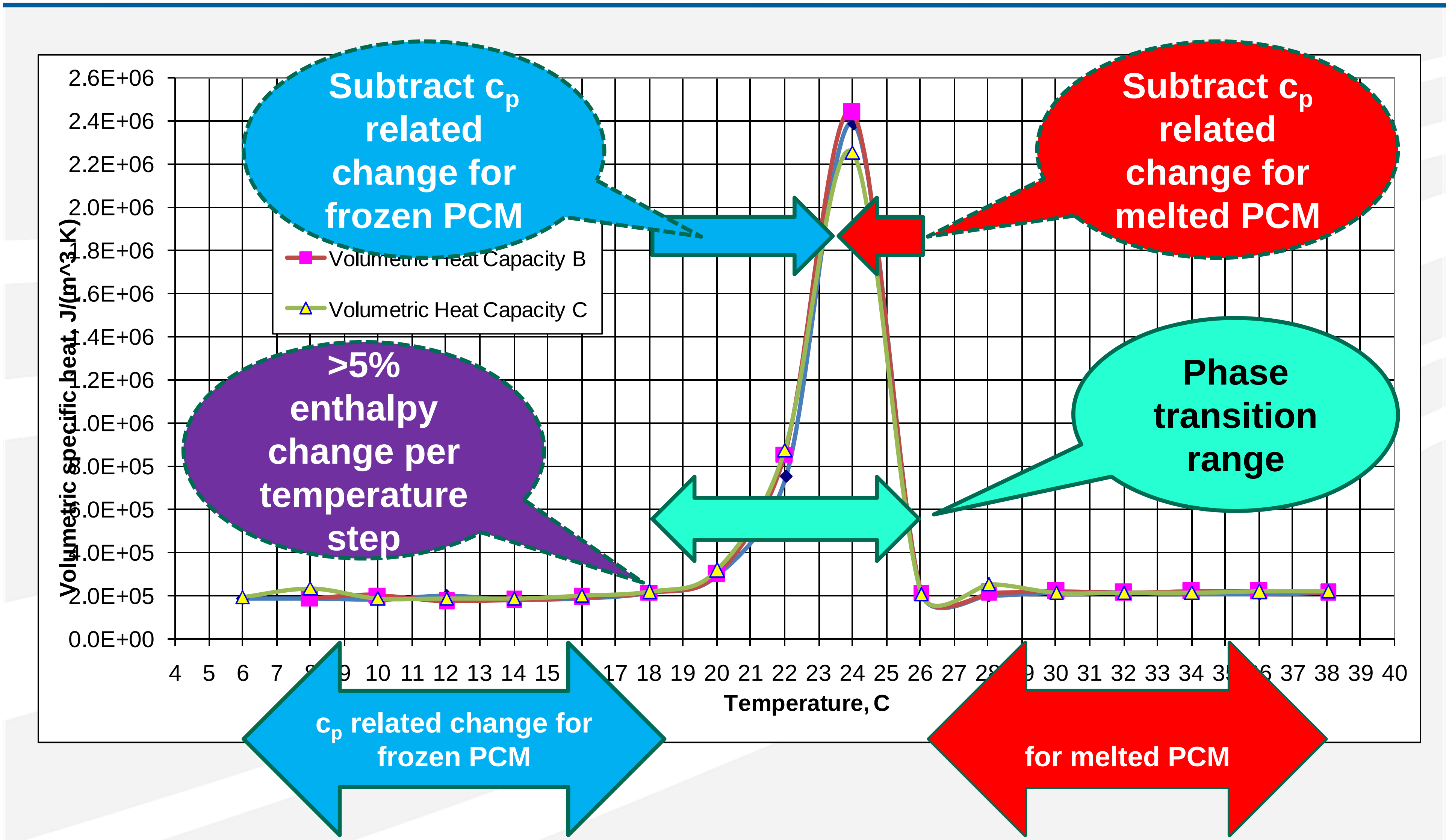
$$c_{eff}(T) = \frac{\partial h}{\partial T}$$

Effective heat capacity, c_{eff}, for a material which is a blend of insulation and PCM may be expressed as

$$c_{eff} = (1-\alpha)c_{ins} + \alpha c_{effPCM}$$

where α denotes the percentage of PCM, c_{ins} the specific heat of insulation without PCM and c_{effPCM} is effective heat capacity of PCM.

Practical determination of M-value based on the DHFMA data



New energy performance label for PCM-enhanced products

M-value → $M_{T_L}^{T_U}$ [J/g]

Future Work within Building America Program

- Dynamic testing of PCM-enhanced materials used in the U.S.
- Development of Energy Plus and BEopt modules enabling modeling of the PCM-enhanced building assemblies
- Comparisons of DHFMA data against DSC or T-history test data
- Modeling leading to optimization of the temperature range and PCM load – as a function of application thermal conductivity, location, and thickness
- Development of configuration recommendations for PCM applications in basic U.S. climates

Thank You!

Any questions ?